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Effect of Shifting Cultivation on Soil Quality Index and Nitrogen Mineralisation of Forest Ecosystem of Manipur, North East India

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ABSTRACT
Shifting cultivation, also referred to as slash and burnt agriculture, was a rather extensive farming system that incorporates both cropping and fallow periods in its land rotation. Changes in land use have a marked effect the soil fertility, soil nutrient dynamics and long term sustainability and for their influence in the atmospheric CO_2 concentration and global warming. Physico-chemical characteristics of soil in slash and burnt site, fallow land and protected forest have been studied. Soil temperature was maximum in slash and burnt site 20.97^{o}C followed by fallow lands 19.60^{o}C and minimum in protected forest site 19.55^{o}C. However, this trend was reversed for soil moisture which was minimum in slash and burnt site 17.46% followed by fallow land 18.57% and maximum in protected forest 19.26%. In the present study the nutrient status, i.e. soil organic C, nitrogen and total phosphorous, of soil in slash and burnt site was higher than other sites which may be attributed due to addition of ash and partly burnt material. The C/N ratio in slash and burnt site, fallow land and protected forest sites were 8.06, 4.89 and 5.22, respectively. The rate of ammonification, nitrification and N-mineralisation was maximum in rainy season in all the four study sites and minimum in winter season except in site I. There was significant correlation between the rates of ammonification, nitrification and N-mineralisation with soil parameters such as moisture, organic carbon, total nitrogen, temperature and pH. High amounts of nutrient in soil under shifting cultivation are lost through leaching, runoff and soil erosion if not uptaken by the crops. Thus, the stability of shifting cultivation system depends upon recovery and maintenance of soil fertility. If the nutrients lost or displaced during the cropping phase are restored during the fallow phase, the system could continue sustainably.

Key words: Slash and burn agriculture, fallow land, ammonification, nitrification, nitrogen mineralisation

INTRODUCTION

Shifting cultivation, which is also often referred to as slash and burnt agriculture, is a rather extensive farming system that incorporates both cropping and fallow periods in its land rotation (Nye and Greenland 1960, Kunstader and Chapman 1978). Slashing and burning of vegetation is a part of shifting cultivation system which is generally known as Jhum. It is an age old traditional agriculture practice is still a very common form of agriculture in north-east India. However, increased population pressure and reduction in the availability of potential arable land has resulted in a more intensive land use. At present, traditional shifting cultivation system with short cropping and long/adequate fallow periods are changing to short fallow and almost continuous land use systems. This change in the pattern of shifting cultivation systems have also been reported from other parts of the world where this system is being practiced (Funakawa et al. 1997, Tanaka et al. 1998, Zodinpuii 2016, Baul et al. 2023, Shibata et al. 2023) and may cause irreversible degradation of soil fertility.

The stability of shifting cultivation system depends upon the recovery and maintenance of soil fertility. If the nutrients lost or displaced during the cropping phase are replenished during the fallow phase, the system could continue sustainably. However, maintenance of soil fertility under shifting cultivation is a serious problem because large fractions of nutrients freed after the slash and burn treatment are lost, through leaching, runoff and soil erosion if not uptaken by the crop plants (Tawenga et al. 1997).

Jhuming is practiced by almost all the tribes of north-eastern region of India and is a major occupation of the people of the region. More than 70,000 families of Manipur are at present practicing Jhuming annually. The trend of declining forest cover is evident in north-eastern India including Manipur, where the forest cover is 16,846 km^2 (75.46%) of the total geographical area of the state in 2019 (Anonymous 2019) as compared to 17,418 km^2 (78.01%) of the total geographical area of the state in 2017 (Anonymous 2017). Thus the development of sustainable agricultural systems and the conservation of remnant forest cover has become a matter of prime importance. A comprehensive understanding of shifting cultivation is indispensable to achieve those objectives because shifting cultivation is still the main form of agriculture in many rural communities (Tanaka et al. 2004).

Land use change is the dominant component of global change in terms of its impact on terrestrial ecosystems. Such a change and particularly the conversion of native land to agriculture profoundly alter land cover, biota and biogeochemical cycles (Walker and Steffen 1999, Grunzweing et al. 2003). Population pressure and intensive land use results in higher rates of land conversion from forest to pasture or agriculture. Such a change causes soil degradation followed by abandonment of land. Since shifting cultivation is widely practiced in the tropics and subtropics, raising human population and growing agricultural practices lead to an increasing decline in the forest cover.

The physical and chemical properties of soil changes due to change in land use pattern. Differential erosion of soil particles of various sizes or exposure of contrasting subsoil horizons alters the physical properties of the surface soil. Chemical properties are affected by erosion, leaching and removal of nutrient elements in alternate land use systems and by accelerated oxidation of organic matter. Such changes have been well documented by Srivastava et al. (1991) and Singh et al. (1991, 1995).

Nitrogen mineralisation is of crucial importance in maintaining the cycling of essential nutrients and ensuring continued productivity of terrestrial ecosystem. Substrate quality and quantity, environmental conditions and soil microorganisms control soil dynamics (Standford and Smith 1972, Gonclaves and Caryle 1994). Nitrogen mineralisation is the microbial conversion of soil organic nitrogen to NH_4-N which in turn may be oxidized to NO_3-N (Vitousk et al.1982, Usman et al. 1998). Thus, the process of N-mineralisation consists of ammonification plus nitrification. Ammonification is carried out by a wide range of microrganisms whereas nitrification is carried out by both autotrophic and heterotrophic organisms (Jussy et al. 2002).

Nitrogen is one of the key elements in shifting cultivation system which is dependent upon the recovery and maintenance of soil fertility. There have been several studies both in India and abroad, on on the behavior of N in Latin America (Sanchez 1982), on immediate effects of burning on soil N-dynamics and microbes *in situ* (Kovacic et al. 1986), on the changes in soil fertility associated with burning (Andriesse and Schelhaas 1987), on the impact of shortened intervals on jhum cycle on species regeneration (Ramkrishnan and Vitousek 1989), on changes in soil fertility on jhum fallows in Mizoram, north east India (Tawenga et al. 1997), on effect of burning on soil organic matter content and N-mineralisation under shifting cultivation of Karen people in northern Thailand (Tanaka et al. 2001). However, little information is available on extensive and detailed studies of soil N-dynamics under shifting cultivation systems, especially on fallow land after cultivation. Therefore, the present study is undertaken to estimate the N-mineralisation dynamics in recent slash and burn (site I), three year old fallow (site II), seven year old fallow (site III) and protected forest (site IV).

Study of physico-chemical properties under shifting cultivation system have been reported in different part of world Getachew et al. (2012) from Ethiopia, Osman et al. (2013) from Bandarban hill district, Bangladesh, Mishra et al. (2017, 2021) from the north-eastern Himalayan region, India, Dutta et al. (2017), Upadhaya et al. (2020), Temjen et al. (2022) from Nagaland, India. However, limited information is available the effect of shifting cultivation on the physico-chemical characteristics

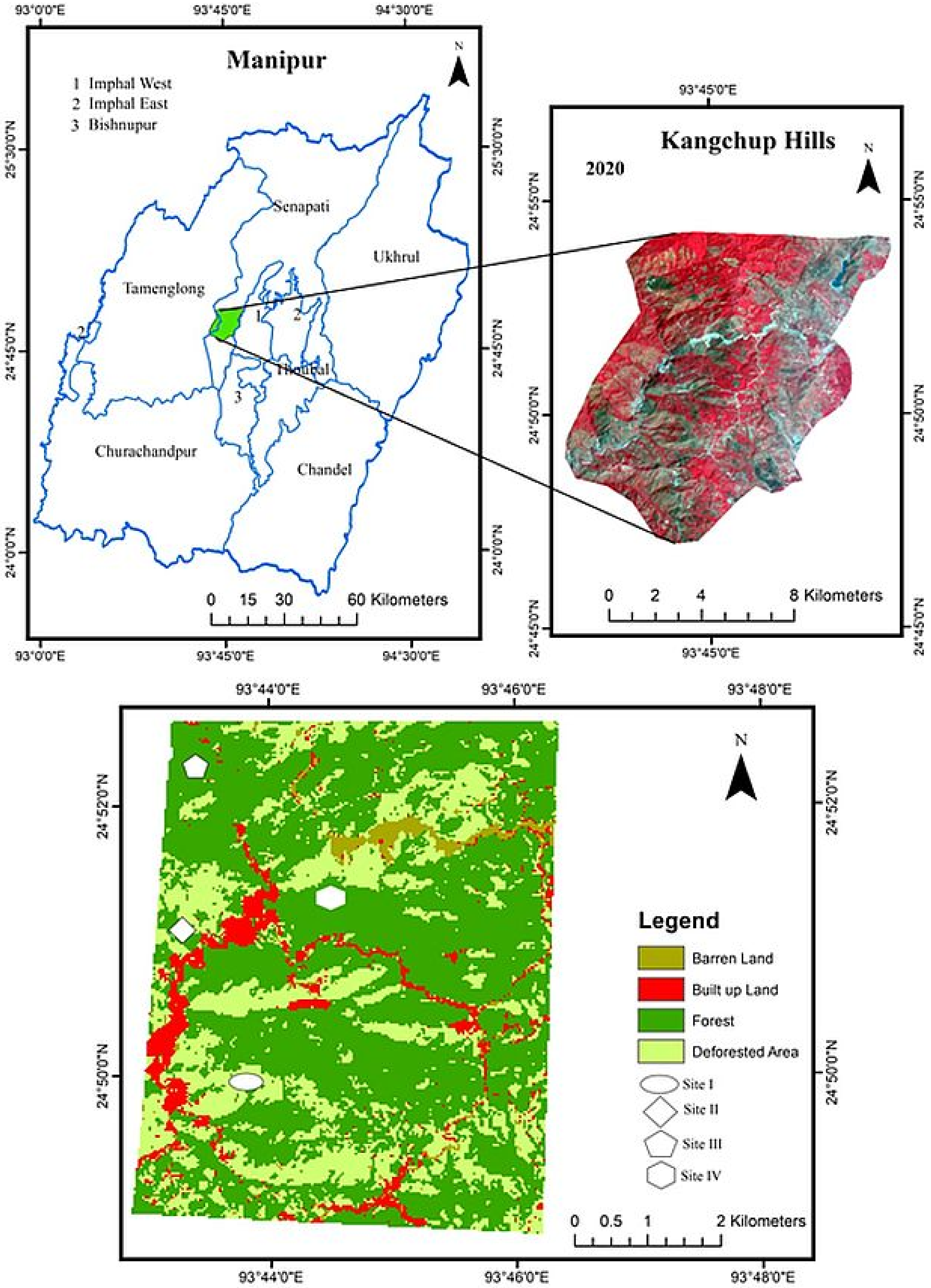

Figure 1. Location of the study area

of soils for Manipur. The objectives of the present study is to understand the effect of shifting cultivation on the physico-chemical characteristics of soils owing to slash and burning of *Castanopsis tribuloides* and *Quercus delbata* dominated forest of Kangchup hill, Manipur, north east, India.

MATERIALS AND METHODS

Site description

The study sites are located in the Kangchup Hills between 24°502 N - 24°552 N latitude and 93°452 - 93°502 E longitude in Senapati District about 14 Km from Imphal town at an altitude ranging from 902 to 944 m above sea level. Study area map was prepared using the Landsat 8 satellite image acquired on 1st April 2020 with 30 m resolution from USGS (Fig.1). The climate of the area is monsoonal with warm wet summer, a distinct rainy season and cool dry winter. There are three distinct seasons comprising of mild summer March-May, rainy season June-October and winter November-February. However, March is the transition month between winter and summer whereas November is the transition month between rainy and winter seasons. The mean monthly maximum temperature ranges between 22.3 to 31°C and the mean monthly minimum temperature ranges between 5.8 to 22.2°C. Average annual rainfall of the area is 1253 mm with 80% occurring during the rainy season. The study was conducted at four different sites i.e., Slash and burn site (site I), three year old fallow site (site II), seven year old fallow site (site III) and a protected forest site (site IV) dominated by *Castanopsis tribuloides* and *Lithocarpus delbata*. The slash and burning operation at site I was done by the local people three months before the onset of the experimental work to prepare the land for shifting cultivation.

Soil sampling, physico-chemical characteristics and N-mineralisation

Physico-chemical characters of soil in different sites were determined seasonally from March 2018 to February 2019. The soil samples were collected by using soil corer from different depths of 0-10 and 10-20 cm soil layers. The soil samples were air dried, crushed and passed through a 2 mm sieve to remove stone, coarse roots and other recognisable plant debris. Powdered soil samples were used for physic-chemical analysis.

Soil texture was analysed by international pipette method (Poonia et al. 1972). Soil moisture by Gravimetric method oven dry at 105°C for 24 hrs, soil temperature by a soil thermometer and soil pH 1:5 soil: water ratio by digital pH meter. The bulk density is the weight of oven dry soil per unit volume which usually expressed in g cm^{-}. Soil organic carbon was analysed by modified Walkley Black's Method and total soil N was determined by Kjeltec ™ 2100 and total soil phosphorus by FIASTAR 5000 Foss Tecator AB, Sweden.

In situ nitrogen mineralisation was measured at monthly intervals by using buried bag technique (Eno 1960). The soil samples were collected from depths of 0-10 cm and 10-20 cm soil layer from five different plots of each study sites using a steel corer 6.5 cm diameter. A part of ach soil samples were sealed in sterilized polyethylene bags after removing coarse stones, roots and large recognizable organic debris and incubated in soil at 0-10 and 10-20 cm depth. After one month, the buried bags were retrieved and analyzed for final ammonification and nitrate concentration. The second part of each soil sample was brought to the laboratory for the measurement of initial inorganic-N NH_4-N and NO_3-N. Each sample was sieved 2 mm to remove stone, coarse roots and other recognizable plant debris. The initial and incubated soil samples were analyzed in 2 M KCl soil extracts by FIASTAR 5000 Flow Injection Analyzer Foss Tecator AB, Sweden. The changes in ammonium and nitrate concentration from the corresponding final concentration and the resultant values are referred to as ammonification and nitrification rates. The net N-mineralisation rate was calculated as the sum of changes in extractable ammonium-N and nitrate-N over one month.

N mineralisation rate = NH_4^--N+NO_3^--N

Where, NH_4^-N is the difference between NH_4^-N at the time t+1 i.e. after one month and time t i.e. fresh samples in the uncovered core, and NO_3^--N is the difference between NO_3^--N at the time t+1 i.e. after one month and time t i.e. fresh samples in the uncovered cores.

RESULTS AND DISCUSSION

Soil moisture

Soil moisture ranged between 10.30 to 24.50% in 0-10 cm and 10.40 to 26.80% in the 10-20 cm of site I (slash and burn site); 9.00 to 27.30% in 0-10 cm and 10.20 to 29.50% in 10-20 cm in site II (three year old fallow); 10.00 to 28.50% in 0-10 cm and 9.05 to 26.20% in 10-20 cm layer in site-III (seven year old fallow) and 12.00 to 26.50% in 0-10 cm and 11.00 to 30.10% in 10-20 cm in site IV (protected forest) (Table 1, 2, 3, 4).

Seasonally, soil moisture content was maximum during the rainy season followed by summer and winter seasons in all the four study sites at both the soil depths 0-10 and 10-20 cm. Soil moisture levels were minimum in December and January coinciding with the cold dry period (Fig. 2). The mean soil moisture level was slightly higher in site IV (17.88%) compared to site I (16.37%) which may be due to lack of vegetation cover and more exposure to sunlight leading to higher evaporation in site I. In contrast, thick plant covers in the site IV reduced evaporation and thereby retention of soil moisture resulting in higher soil moisture levels. The single most powerful control on the rate of chemical and biological processes in the soil is the soil water content. It is the medium in which transport of elements and particles occurs within the ecosystem (Scholes et al. 1994).

Soil pH

Soil pH in site I varied between 5.00 to 6.81 in 0-10 cm layer and 5.70 to 6.80 in 10-20 cm layer. In site II, it varied between 4.80 to 6.30 in 0-10 cm layer and 4.95 to 5.85 in 10-20 cm layer. In site III, it varied between 4.80 to 6.10 in 0-10 cm layer and 4.85 to 5.55 in 10-20 cm layer and in site IV, the soil pH ranged between 4.80 to 5.80 in 0-10 cm and 4.81 to 5.65 in 10-20 cm soil layer. Soil pH value was high during rainy season followed by summer and winter seasons across all the soil depths (Fig. 3).

Mean soil pH was high in site I and low in site IV, indicating more acidity in the later. The comparatively high pH at site I may be due to incorporation of burnt organic matter or ash in the soil and also due to cations freed after burning of standing vegetation and release of humic acid during decomposition. Nye and Greenland (1964) recorded a rise in pH from 5.2 to 8.1 and Lai and Cummings (1979) from 6.6 to 9.0 in top 5 cm soil layer soon after burning. Several researchers have also cited ash input as the reason for increase of soil pH or decreased in soil acidity (Kyuma et al. 1985, Ramakrishnan 1992, Ulery et al.1993, Tawenga et al.1997, Tanaka et al.1997).

The more acidic nature of the soils under forest may be due to depletion of exchangeable bases as these were rapidly absorbed by herbaceous species and tree species. Soil pH is recognized as an important regulator of microbial activity. The pH values recorded in this study were comparable with the ranges reported by Motavalli et al. (1995) (3.91-6.69), Tawnenga et al. (1997) (5.70-7.00), Tanaka et al. (1998) (5.10-6.50) and Ross et al. (1999) (5.40-5.70).

Soil temperature

Soil temperature ranged between 15.50 to 28.00^{o}C in 0-10 cm and 15.50 to 22.50^{o}C in 10-20 cm in site I, 18.50 to 23.50^{o}C in 0-10 cm and 15.50 to 23.50^{o}C in 10-20 cm in site II; 16.50 to 24.40^{o}C in 0-10 cm and 17.00 to 23.00^{o}C in 10-20 cm in site III and 16.00 to 23.50^{o}C in 0-10 cm and 15.50 to 22.50^{o}C in 10-20 cm in site IV.

Soil temperature, seasonally, was maximum during the rainy season followed by summer and winter seasons in both the soil depths in all the study sites (Fig 4). Maximum soil temperature in the rainy season coincides with raising air temperature in July and August, probably because heat conductivity is higher in wet soil than that of dry soil Debano et al. (1998).

The higher mean annual temperatures recorded at site I 20.65 to 21.06^{o}C may be due to lack of vegetation cover after the slash and burn treatment leading to direct exposure to solar radiation for much longer periods than the other sites. Increased temperature can alter ecosystem processes such as soil organic matter mineralisation dynamics, which in turn further affects species growth and establishment (Pastor and Post 1986, Running and Nemoni 1991).

Bulk density

Bulk density values of soil ranged between 1.29 to

Table 1. Correlation between ammonification, nitrification, mineralisation and soil properties in the recent slash and burnt site (site I)

Variables	Soil depth (cm)	r	y	df	t	p	Variability (%)
Ammonification							
Soil moisture (SM)	0-10	0.96	-2.36+0.24x	10	10.25	$p<0.01$	92.16
	10-20	0.7	0.39+0.19x	10	3.12	$p<0.05$	49.00
Soil organic carbon	0-10	0.94	-0.35+2.13x	10	8.39	$p<0.01$	88.36
(SOC)	10-20	0.93	1.77+1.76x	10	8.09	$p<0.01$	86.94
Total soil nitrogen	0-10	0.94	-2.96+27.58x	10	8.67	$p<0.01$	88.36
(TSN)	10-20	0.7	0.42+26.94x	10	3.06	$p<0.05$	49.00
Soil temperature (ST)	0-10	0.87	-14.73+3.42x	10	5.49	$p<0.01$	75.69
	10-20	0.84	-7.26+0.58x	10	4.83	$p<0.01$	70.56
pH	0-10	0.73	-5.06+0.44x	10	3.36	$p<0.01$	53.29
	10-20	0.89	-20.09+3.90x	10	6.21	$p<0.01$	79.21
Nitrification							
Soil moisture (SM)	0-10	0.95	-1.90+0.33x	10	9.75	$p<0.01$	90.25
	10-20	0.77	0.60+0.2x	10	3.8	$p<0.01$	59.29
Soil organic carbon	0-10	0.78	0.27+1.34x	10	3.95	$p<0.01$	60.84
(SOC)	10-20	0.97	0.94+1.74x	10	12.13	$p<0.01$	94.09
Total soil nitrogen	0-10	0.8	-1.5+17.78x	10	4.27	$p<0.01$	64.00
(TSN)	10-20	0.73	-0.41+26.74x	10	3.36	$p<0.01$	53.29
Soil temperature (ST)	0-10	0.84	-5.18+0.39x	10	4.98	$p<0.01$	70.56
	10-20	0.85	-7.71+0.55x	10	5.1	$p<0.01$	72.25
pH	0-10	0.98	-13.2+2.91x	10	15.46	$p<0.01$	96.04
	10-20	0.96	-21.43+3.98x	10	10.58	$p<0.01$	92.16
Mineralisation							
Soil moisture (SM)	0-10	0.95	-2.99+0.73x	10	10.07	$p<0.01$	90.25
	10-20	0.75	-0.21+0.38x	10	3.55	$p<0.01$	56.25
Soil organic carbon	0-10	0.91	0.47+3.35x	10	6.96	$p<0.01$	82.81
(SOC)	10-20	0.96	2.70+3.5x	10	11.44	$p<0.01$	92.16
Total soil nitrogen	0-10	0.90	-3.41+42.67x	10	6.45	$p<0.01$	81.00
(TSN)	10-20	0.72	0.007+53.68x	10	3.3	$p<0.01$	51.84
Soil temperature (ST)	0-10	0.75	-7.84+0.74x	10	3.57	$p<0.01$	56.25
	10-20	0.86	-14.97+1.13x	10	5.24	$p<0.01$	73.96
pH	0-10	0.91	-24.81+5.84x	10	7.16	$p<0.01$	82.81
	10-20	0.94	-41.52+7.88x	10	8.56	$p<0.01$	88.36

1.36 g cm^{-3} in 0-10 cm and 1.31 to 1.38 g cm^{-3} in 10-20 cm soil layer at site I. In site II, it ranged between 1.30 to 1.39 g cm^{-3} in 0-10 cm and 1.34 to 1.40 g cm^{-3} in 10-20 cm layer. However, in site III, it varied between 1.34 to 1.38 g cm^{-3} in 0-10 cm and 1.34 to 1.41 g cm^{-3} in 10-20 cm soil layer and in site IV, 1.34 to 1.41 g cm^{-3} in 0-10 cm and 1.35 to 1.45 g cm^{-3} in 10-20 cm soil layer.

The low bulk density in the uppermost soil layer (0-10 cm) and increase with increase in the depth of soil may be attributed to the presence of organic matter in the upper soil layer in the form dead organic biomass which decomposes to form humus that binds soil particle to form more soil aggregate (Fig. 5). Franzluabbers (1999) also reported lower bulk density in the upper soil layers than the deeper soil layers from an eroded upland landscape of Franington USA.

Table 2. Correlation between ammonification, nitrification, mineralisation and soil properties in the three year old fallow (site II)

Variables	**Soil depth (cm)**	**r**	**y**	**df**	**t**	**p**	**Variability (%)**
Ammonification							
Soil moisture (SM)	0-10	0.92	1.04+0.1x	10	7.4	p<0.01	84.64
	10-20	0.86	0.91+0.06x	10	5.31	p<0.01	73.96
Soil organic carbon	0-10	0.67	1.82+1.67x	10	2.88	p<0.05	44.89
(SOC)	10-20	0.77	1.45+1.88x	10	3.86	p<0.01	59.29
Total soil nitrogen	0-10	0.65	0.17+19.45x	10	2.7	p<0.05	42.25
(TSN)	10-20	0.84	1.07+13.15x	10	4.96	p<0.01	70.56
Soil temperature (ST)	0-10	0.89	-5.96+0.42x	10	6.02	p<0.01	79.21
	10-20	0.85	-1.22+0.18x	10	5.18	p<0.01	72.25
pH	0-10	0.79	-3.54+1.2x	10	4.07	p<0.01	62.41
	10-20	0.77	-6.65+1.64x	10	3.83	p<0.01	59.29
Nitrification							
Soil moisture (SM)	0-10	0.83	-0.65+0.20x	10	4.78	p<0.01	68.89
	10-20	0.79	0.37+0.88x	10	4.08	p<0.01	62.41
Soil organic carbon	0-10	0.88	0.08+4.87x	10	5.8	p<0.05	77.44
(SOC)	10-20	0.7	1.13+2.55x	10	3.06	p<0.01	49.00
Total soil nitrogen	0-10	0.78	-4.13+52.29x	10	3.96	p<0.01	60.84
(TSN)	10-20	0.82	0.49+19.36x	10	4.62	p<0.01	67.24
Soil temperature (ST)	0-10	0.84	-15.75+0.90x	10	4.95	p<0.01	70.56
	10-20	0.92	-3.37+0.29x	10	7.31	p<0.01	84.64
pH	0-10	0.96	-14.34+3.27x	10	11.24	p<0.01	92.16
	10-20	0.86	-12.64+2.75x	10	5.28	p<0.01	73.96
Mineralisation							
Soil moisture (SM)	0-10	0.91	0.39+0.3x	10	7.04	p<0.01	82.81
	10-20	0.84	1.75+0.13x	10	4.8	p<0.01	70.56
Soil organic carbon	0-10	0.86	1.91+6.54x	10	5.41	p<0.01	73.96
(SOC)	10-20	0.75	2.87+3.96x	10	3.65	p<0.01	56.25
Total soil nitrogen	0-10	0.79	-3.96+71.77x	10	4.02	p<0.01	62.41
(TSN)	10-20	0.84	2.01+28.26x	10	0.95	p<0.01	70.56
Soil temperature (ST)	0-10	0.91	-21.71+1.33x	10	6.85	p<0.01	82.81
	10-20	0.91	-3.38+0.41x	10	6.92	p<0.01	82.81
pH	0-10	0.96	-17.87+4.46x	10	11.48	p<0.01	92.16
	10-20	0.82	-15.66+3.74x	10	4.46	p<0.01	67.24

Soil organic carbon

Soil organic carbon ranged between 0.75 to 4.05% in 0-10 cm and 0.35 to 2.60% in 10-20 cm soil layer at site I, 0.15 to 1.08% in 0-10 cm and 0.14 to 0.80% in 10-20 cm soil layer at site II, 0.20 to 1.38% in 0-10 cm and 0.25 to 0.95% in 10-20 cm soil layer at site III and 0.50 to 3.66% in 0-10 cm and 0.30 to 0.93% in 10-20 cm soil layer at site IV.

Higher values of organic carbon were recorded in the upper soil layer of 0-10 cm depth and it decreased with the increase in soil depth in all the four study sites. Similar pattern of soil organic carbon was also reported from different ecosystems (Tawenga et al.1997, Ross et al. 1999, Zhong and Qigyo 2001, Yemfack et al. 2002, Castelli and Lazzari 2002, Singh et al. 2003, Devi and Yadava

Table 3. Correlation between ammonification, nitrification, mineralisation and soil properties in the three year old fallow (site III)

Variables	**Soil depth (cm)**	**r**	**y**	**df**	**t**	**p**	**Variability (%)**
Ammonification							
Soil moisture (SM)	0-10	0.85	$0.18+0.2x$	10	5.15	$p<0.01$	72.25
	10-20	0.79	$0.33+0.08x$	10	4.03	$p<0.01$	62.41
Soil organic carbon (SOC)	0-10	0.88	$1.67+3.34x$	10	5.92	$p<0.01$	77.44
	10-20	0.64	$1.02+1.55x$	10	2.65	$p<0.05$	40.96
Total soil nitrogen (TSN)	0-10	0.78	$-0.67+32.3x$	10	3.95	$p<0.01$	60.84
	10-20	0.61	$0.44+12.08x$	10	2.43	$p<0.01$	37.21
Soil temperature (ST)	0-10	0.89	$-5.5+0.47x$	10	6.12	$p<0.01$	79.21
	10-20	0.69	$-2.45+0.23x$	10	3.03	$p<0.05$	47.61
pH	0-10	0.96	$-13.84+3.4x$	10	10.59	$p<0.01$	92.16
	10-20	0.65	$-6.45+1.61x$	10	2.74	$p<0.05$	42.25
Nitrification							
Soil moisture (SM)	0-10	0.89	$-0.8+0.17x$	10	6.3	$p<0.01$	79.21
	10-20	0.70	$0.06+0.17x$	10	3.13	$p<0.05$	49.00
Soil organic carbon (SOC)	0-10	0.90	$0.59+2.29x$	10	6.54	$p<0.01$	81.00
	10-20	0.88	$0.38+5.44x$	10	5.82	$p<0.01$	77.44
Total soil nitrogen (TSN)	0-10	0.83	$-1.62+29.27x$	10	4.72	$p<0.01$	68.89
	10-20	0.89	$0.51+34.10x$	10	6.13	$p<0.01$	79.21
Soil temperature (ST)	0-10	0.83	$-4.99+0.37x$	10	4.8	$p<0.01$	68.89
	10-20	0.71	$-4.42+0.39x$	10	3.17	$p<0.01$	50.41
pH	0-10	0.98	$-12.87+2.96x$	10	14.52	$p<0.01$	69.04
	10-20	0.87	$-25.54+5.66x$	10	5.58	$p<0.01$	75.69
Mineralisation							
Soil moisture (SM)	0-10	0.87	$0.38+0.61x$	10	5.74	$p<0.01$	75.69
	10-20	0.77	$-0.02+0.29x$	10	3.81	$p<0.01$	59.29
Soil organic carbon (SOC)	0-10	0.94	$0.52+8.96x$	10	8.37	$p<0.01$	88.36
	10-20	0.93	$0.14+3.52x$	10	8.13	$p<0.01$	86.49
Total soil nitrogen (TSN)	0-10	0.81	$-2.29+61.45x$	10	4.33	$p<0.01$	65.61
	10-20	0.86	$1.14+51.11x$	10	5.34	$p<0.01$	73.96
Soil temperature (ST)	0-10	0.87	$-10.49+0.84x$	10	5.56	$p<0.01$	75.69
	10-20	0.82	$-8.47+0.7x$	10	4.5	$p<0.01$	67.24
pH	0-10	0.97	$-26.27+6.35x$	10	13.22	$p<0.01$	94.09
	10-20	0.92	$-42.09+9.31x$	10	7.64	$p<0.01$	84.64

2005).

Maximum seasonal value of soil organic carbon was recorded in the rainy season followed by winter and summer seasons in all the four sites in 0-10 cm soil layer. However, in 10-20 cm soil layer maximum SOM value was recorded in rainy season and minimum in winter season (Fig. 6). Maximum value of soil organic carbon in the rainy season may be due to faster decomposition of organic matter due to availability of soil moisture and congenial temperature, whereas in the summer and the winter seasons rate of decomposition was slow resulting in low level of soil organic carbon.

The present value of soil organic carbon 0.13 to 4.05% are comparable with the data reported by Singh et al. (1991) in dry tropical savana U.P. 0.84 to 1.20%, Tawnenga et al. (1997) in second year cropping on Jhum fallows in Mizoram, North-eastern

Table 4. Correlation between ammonification, nitrification, mineralisation and soil properties in the protected forest (site IV)

Variables	**Soil depth (cm)**	**r**	**y**	**df**	**t**	**p**	**Variability (%)**
Ammonification							
Soil moisture (SM)	0-10	0.87	-1.88+0.31x	10	5.76	p<0.01	75.69
	10-20	0.82	-0.53+0.2x	10	4.57	p<0.01	67.24
Soil organic carbon (SOC)	0-10	0.85	2.32+1.64x	10	5.11	p<0.01	72.25
	10-20	0.81	0.72+4.66x	10	4.44	p<0.05	65.61
Total soil nitrogen (TSN)	0-10	0.75	-0.29+24.76	10	3.56	p<0.01	56.25
	10-20	0.64	-0.25+29.85x	10	2.62	p<0.05	40.96
Soil temperature (ST)	0-10	0.77	-8.00+0.62x	10	3.76	p<0.01	59.29
	10-20	0.66	-6.5+0.53x	10	2.8	p<0.01	43.56
pH	0-10	0.73	-19.89+4.85x	10	3.35	p<0.01	53.29
	10-20	0.7	3.39+0.1x	10	3.1	p<0.05	49.00
Nitrification							
Soil moisture (SM)	0-10	0.82	-0.21+0.13x	10	4.57	p<0.01	67.24
	10-20	0.79	0.33+0.08x	10	4.04	p<0.05	62.41
Soil organic carbon (SOC)	0-10	0.71	0.61+1.62x	10	3.22	p<0.01	50.41
	10-20	0.64	1.02+1.55x	10	2.64	p<0.01	40.96
Total soil nitrogen (TSN)	0-10	0.67	0.55+9.7x	10	2.82	p<0.01	44.84
	10-20	0.61	0.44+12.08x	10	2.44	p<0.01	37.21
Soil temperature (ST)	0-10	0.93	-4.26+0.33x	10	7.99	p<0.01	86.49
	10-20	0.69	-2.44+0.23x	10	3.03	p<0.01	47.61
pH	0-10	0.6	-6.39+1.75x	10	2.36	p<0.01	36.00
	10-20	0.65	-6.45+1.61x	10	2.73	p<0.01	42.25
Mineralisation							
Soil moisture (SM)	0-10	0.95	-2.08+0.43x	10	9.72	p<0.01	90.25
	10-20	0.87	-0.20+0.28x	10	56.56	p<0.01	75.69
Soil organic carbon (SOC)	0-10	0.86	4.10+2.19x	10	5.43	p<0.01	73.96
	10-20	0.82	1.71+6.21x	10	4.48	p<0.01	67.24
Total soil nitrogen (TSN)	0-10	0.76	0.65+32.96x	10	3.65	p<0.01	57.76
	10-20	0.67	0.2+41.93x	10	2.89	p<0.01	44.89
Soil temperature (ST)	0-10	0.9	-12.28+0.96x	10	6.44	p<0.01	81.00
	10-20	0.72	-8.95+0.76x	10	3.28	p<0.01	51.84
pH	0-10	0.71	-24.39+6.25x	10	3.21	p<0.01	50.41
	10-20	0.79	-26.32+6.1x	10	4.04	p<0.01	62.41

India 1.80 to 2.65%, Funakawa et al. (1997) in shifting cultivation system from Northern Thailand 1.36 to 3.89%, Kendawang et al. (2004) in shifting cultivation inform Sarawak, Malaysia 0.79 to 6.45%, Devi and Yadava (2005) in *Dipterocarpus* forest of Manipur, India 0.14 to 3.91%. In contrast, Srivastava and Singh (1991), Henrot and Robertson (1994) have showed that soil organic carbon decreased in the alternate land use pattern from forest ecosystems.

High soil organic carbon recorded in site I may be due to the addition of burnt and partly burnt organic matter during slash and burning which causes a conspicuous increase in the content of organic carbon. Low soil organic carbon in site II may be due to short fallow period. Soil organic carbon increased gradually with the age of the natural fallow and fallow length tended to increase both organic

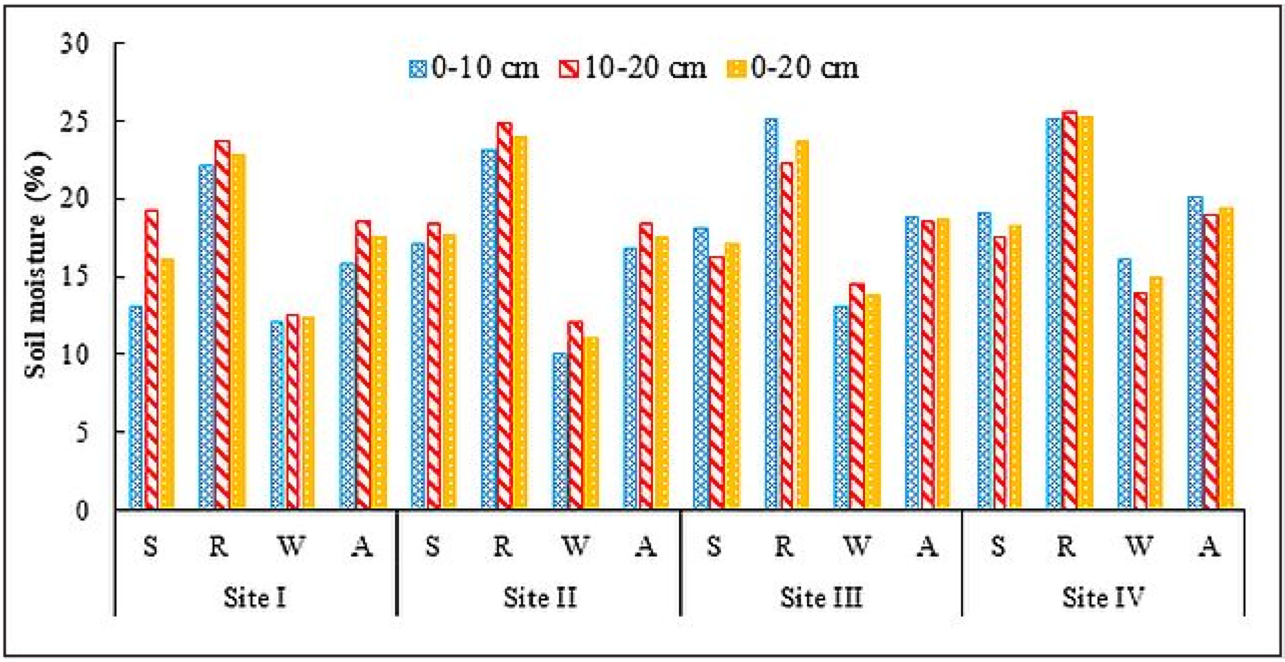

Figure 2. Seasonal variation in the soil moisture in the recent slash and burnt site (site I), three year old fallow (site II), seven year old fallow (site III) and protected forest (site IV). S-Summer; R-Rainy; W-Winter; A-Annual

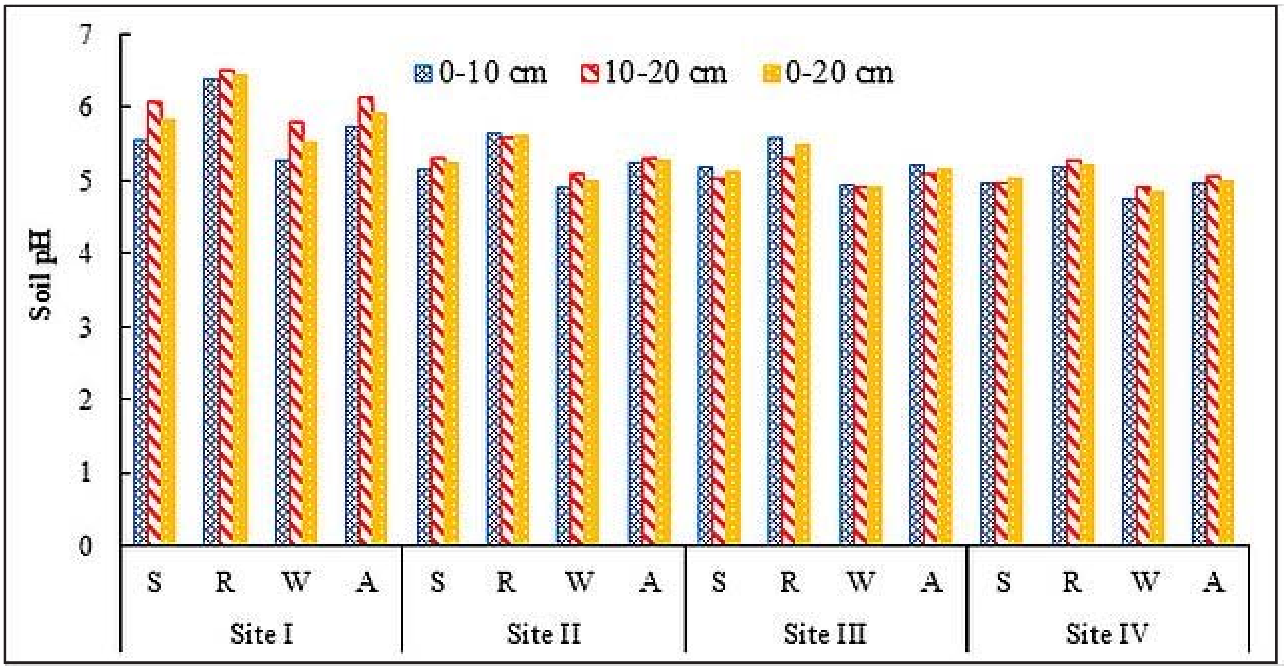

Figure 3. Seasonal variation in the soil pH in the recent slash and burnt site (site I), three year old fallow (site II), seven year old fallow (site III) and protected forest (site IV). S-Summer; R-Rainy; W-Winter; A-Annual

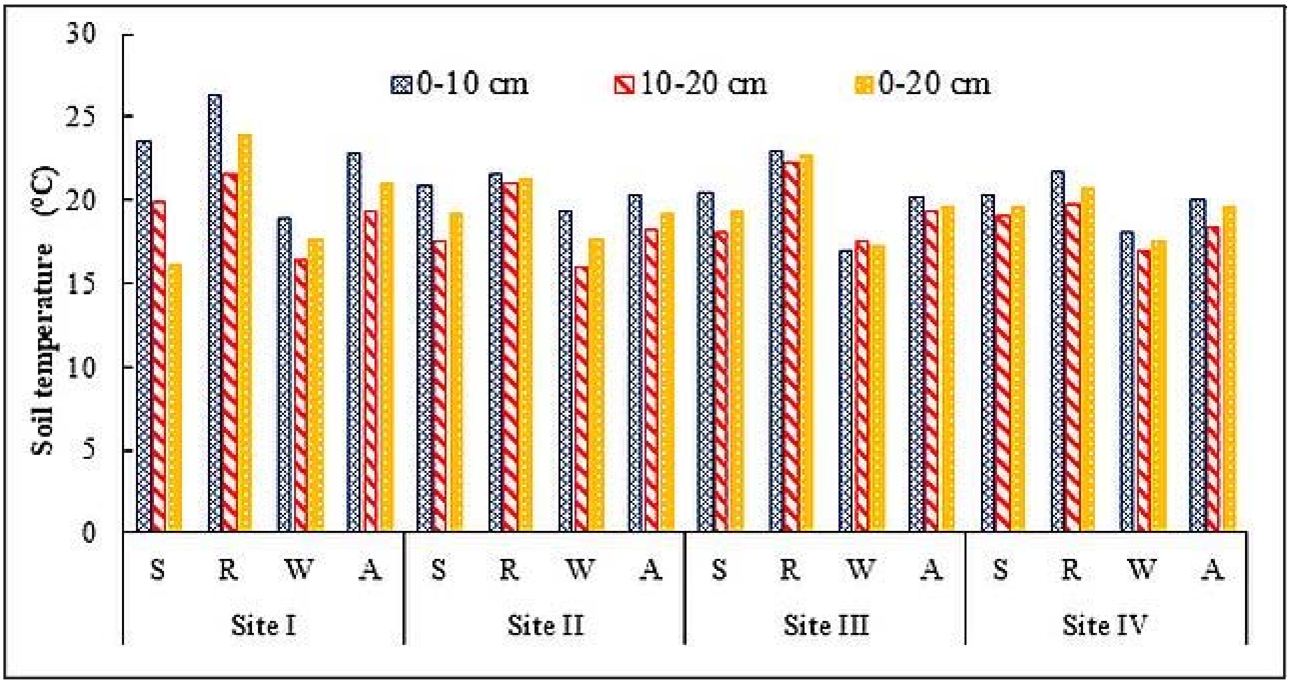

Figure 4. Seasonal variation in the soil temperature in the recent slash and burnt site (site I), three year old fallow (site II), seven year old fallow (site III) and protected forest (site IV). S-Summer; R-Rainy; W-Winter; A-Annual

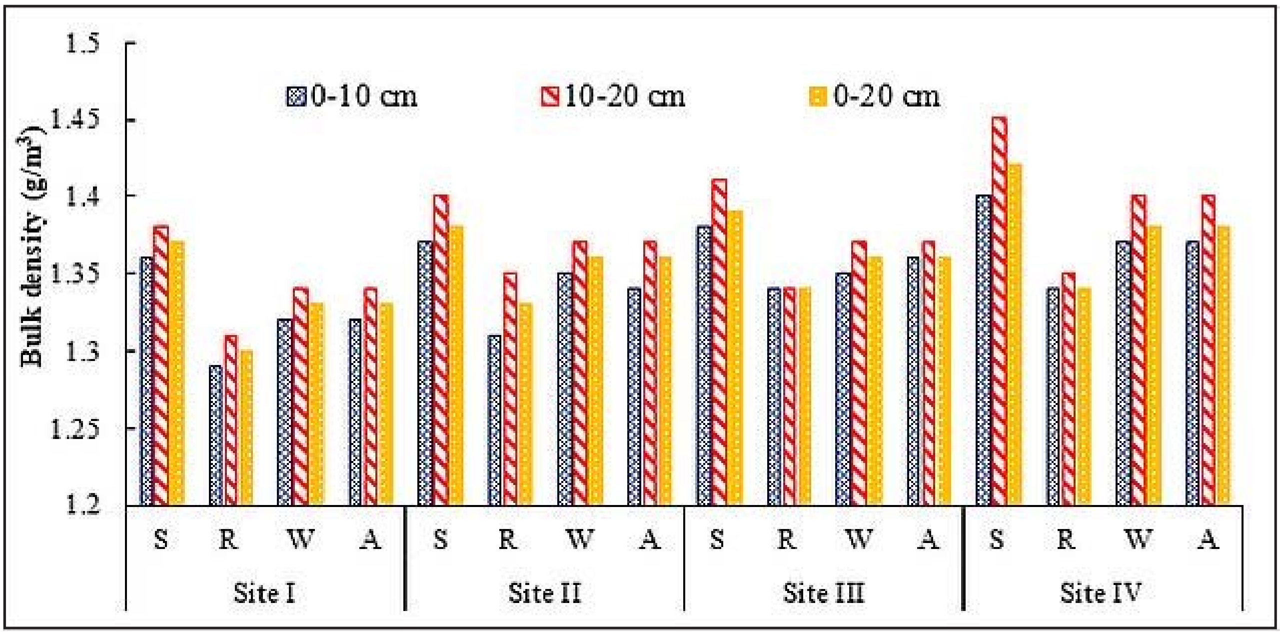

Figure 5. Seasonal variation in the bulk density in the recent slash and burnt site (site I), three year old fallow (site II), seven year old fallow (site III) and protected forest (site IV). S-Summer; R-Rainy; W-Winter; A-Annual

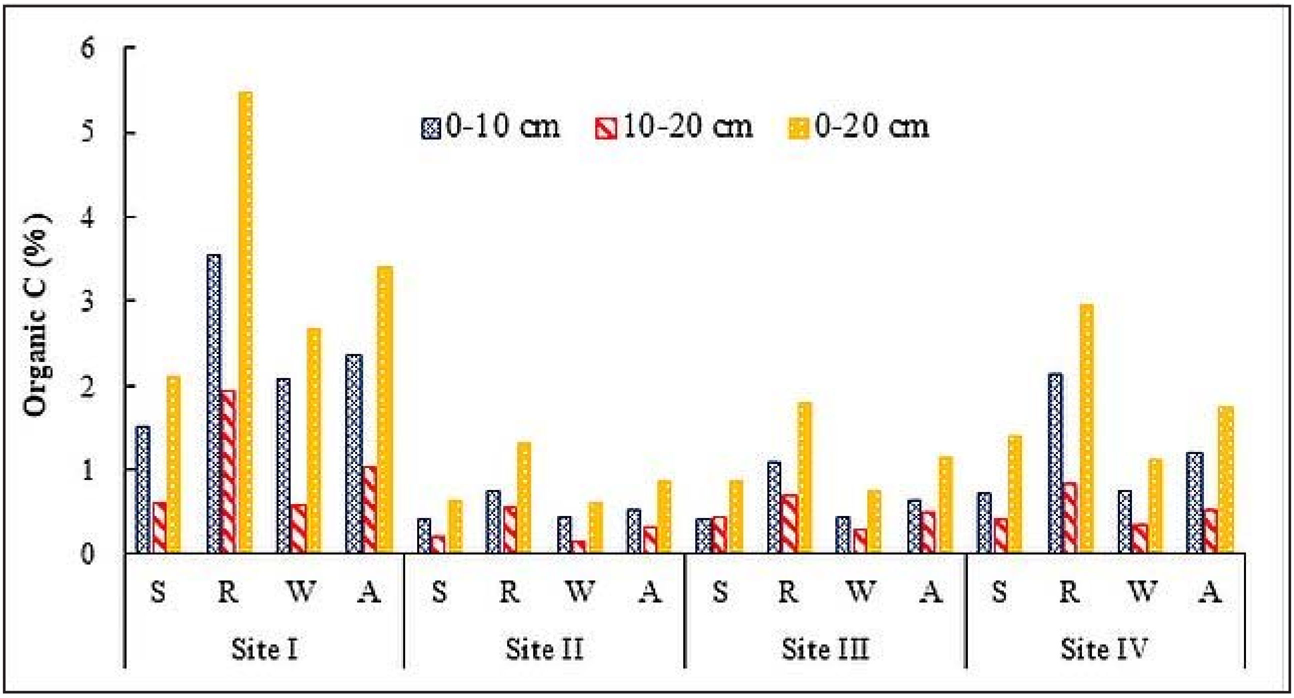

Figure 6. Seasonal variation in the soil organic C (%) in the recent slash and burnt site (site I), three year old fallow (site II), seven year old fallow (site III) and protected forest (site IV). S-Summer; R-Rainy; W-Winter; A-Annual

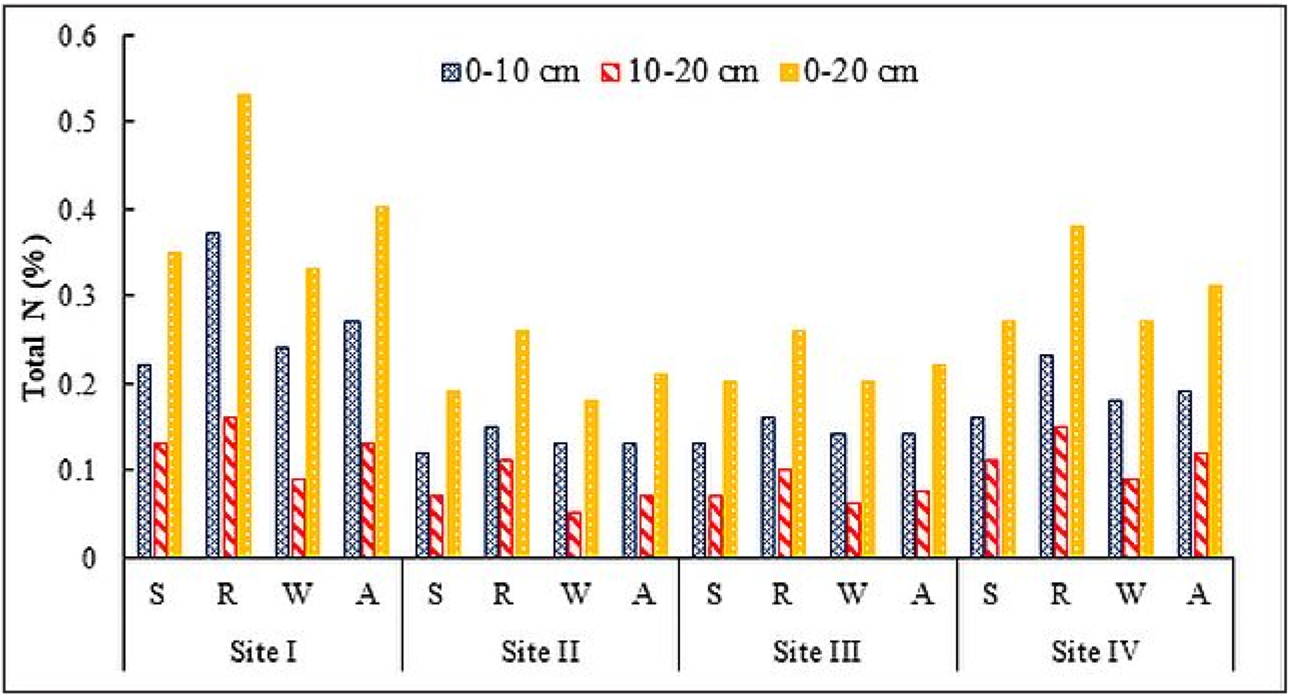

Figure 7. Seasonal variation in the soil Total N (%) in the recent slash and burnt site (site I), three year old fallow (site II), seven year old fallow (site III) and protected forest (site IV). S-Summer; R-Rainy; W-Winter; A-Annual

matter and humic acid content of the soil. Changes in land use can have a marked effect on soil carbon contents as a result of the interactions between changes in detrital inputs and subsequent immobilisation mediated by soil microorganisms. Such changes are important from the view point of soil fertility and long term sustainability and for their influence on atmospheric CO_2 concentration and global warming (Tate 1987, Bouwman 1990).

Total soil N

Total soil nitrogen ranged between 0.16 to 0.41% in 0-10 cm and 0.08 to 0.19% in 10-20 cm soil layer at site I, 0.10 to 0.18% in 0-10 cm and 0.04 to 0.14% in 10-20 cm soil layer at site II, 0.10 to 0.22% in 0-10 cm and 0.04 to 0.16% in 10-20 cm soil layer at site III and 0.13 to 0.28% in 0-10 cm soil layer and 0.10 to 0.19% in 10-20 cm soil layer at site IV. Total soil nitrogen showed monthly fluctuations in all the four study sites at both the soil depths 0-10 and 10-20 cm. Total soil nitrogen was comparatively higher in site I than the other three sites which may be due to burning treatment. Lynhan et al. (1979) also reported increase in total soil carbon and total soil nitrogen following burning. Kyuma et al. (1985) reported an increase in the total soil carbon and total soil nitrogen contents after burning which was ascribed to addition of unburned on partially burned materials in the soil surface. In contrast, Tawenga et al. (1997) reported decrease in total soil carbon and nitrogen content following burning. Variation in N response among studies may be attributed to differences in burning frequency, site quality and organic matter quality.

Total soil nitrogen was found to be higher in the upper layer of soil 0-10cm and it decreases with increase in the depth of soil due to the low availability of organic matter in the lower layers of the soil in all the study sites (Fig. 7). The decline in the concentration of total soil nitrogen with increase in soil depth was also reported by other workers (Pinzari et al. 1998, Ross et al. 1999). In the present study the value of total soil N ranges between 0.02 to 0.41% which is comparable with those from Billore et al. (1995) 0.21 to 0.62% from grassland, deciduous forest and evergreen forests of Central Japan, Howard et al. (1997) 0.03 to 2.40% of total soil N from forests of Canada, Funakawa et al. (1997) 0.07 to 0.48% under shifting cultivation in northern Thailand, Tanaka et al. (1998) 0.19 to 0.55% surface soils under shifting cultivation in Northern Thailand.

Total soil N was maximum during rainy season and minimum in summer season in all the four study sites except in the depth of 10-20 cm, where the minimum total soil nitrogen was recorded in during winter season (Fig. 7). The higher values of total soil N during rainy season may be due to the moist soil and favorable temperature leading to higher rate of organic matter decomposition of newly added organic residues plant litter entering the system in preceding dry season. The low values of total soil N recorded in the summer and winter season may be due to low soil moisture content leading to slow rate of decomposition. Similar results were also reported by Tangtrakarnpong and Vityakon (2002) from north east Thailand.

C:N ratio

The mean value of C: N ratio across the soil depths in different months ranged between 3.94 to 14.10 in site I, 2.25 to 7.38 in site II, 2.74 to 9.84 in site III and 3.09 to 9.85 in site IV due to addition of burnt and partially burnt organic matter during slash and burning (Fig. 8). The present data of C:N ratio are within the values reported by Tanaka et al. (1998) 3.30 to 11.60 from the surface soils under shifting cultivation in Northern Thailand, Devi and Yadava (2005) 1.92 to 18.12 from *Dipterocarpus* forest of Manipur, North East India.

Total phosphorous

Total soil phosphorous ranged between 310 to 680 $\mu g\ g^{-1}$ of soil in 0-10 cm and 229 to 380 $\mu g\ g^{-1}$ of soil in 10-20 cm at site I, 286 to 580 $\mu g\ g^{-1}$ of soil in 0-10 cm and 210 to 323 $\mu g\ g^{-1}$ of soil in 10-20 cm at site II, 295 to 590 $\mu g\ g^{-1}$ of soil in 0-10 cm and 225 to 328 $\mu g\ g^{-1}$ of soil in 10-20 cm at site III and 315 to 650 $\mu g\ g^{-1}$ of soil in 0-10 cm and 224 to 323 $\mu g\ g^{-1}$ of soil in 10-20 cm at site IV throughout the study period.

Seasonally total soil phosphorous was maximum during rainy season followed by winter and summer seasons in both the soil depths 0-10 and 10-20 cm. The high value of total phosphorous during rainy season may be due to the relatively high moisture and temperature conditions which facilitate faster decomposition of organic matter (Fig. 9). In highly

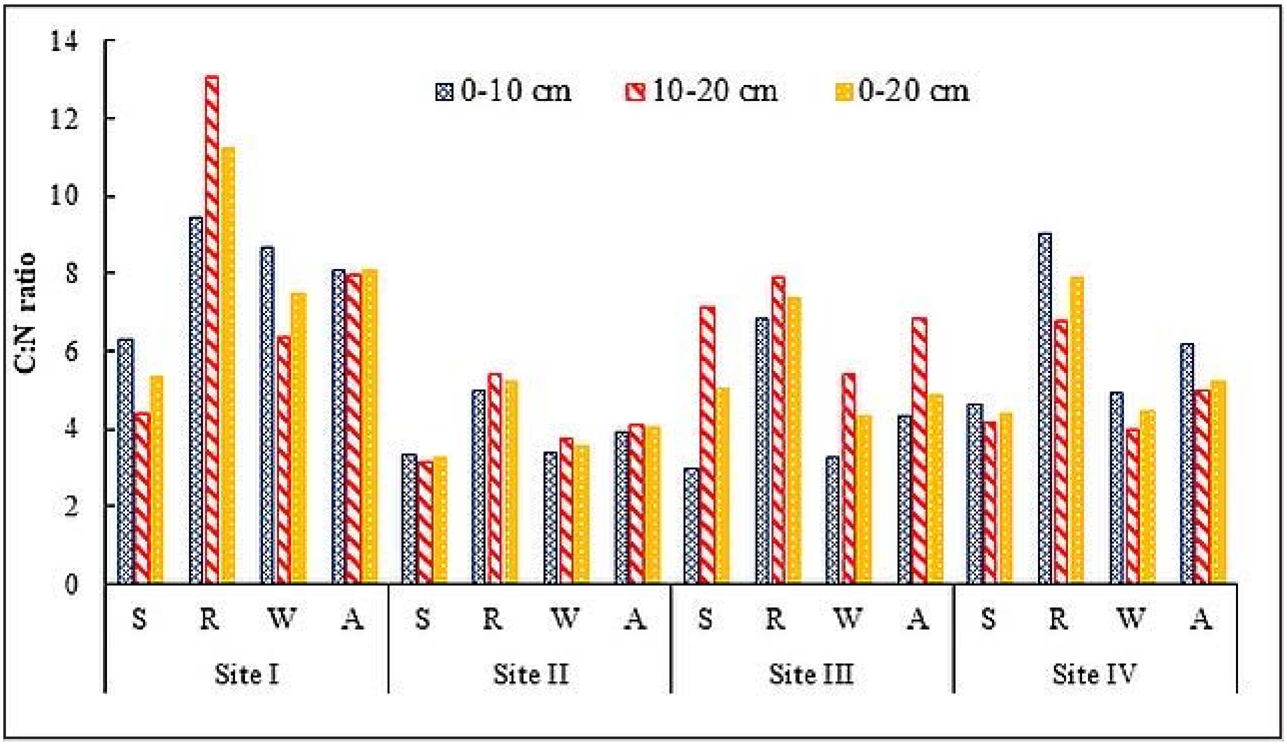

Figure 8. Seasonal variation in the soil C: N ratio in the recent slash and burnt site (site I), three year old fallow (site II), seven year old fallow (site III) and protected forest (site IV). S-Summer; R-Rainy; W-Winter; A-Annual

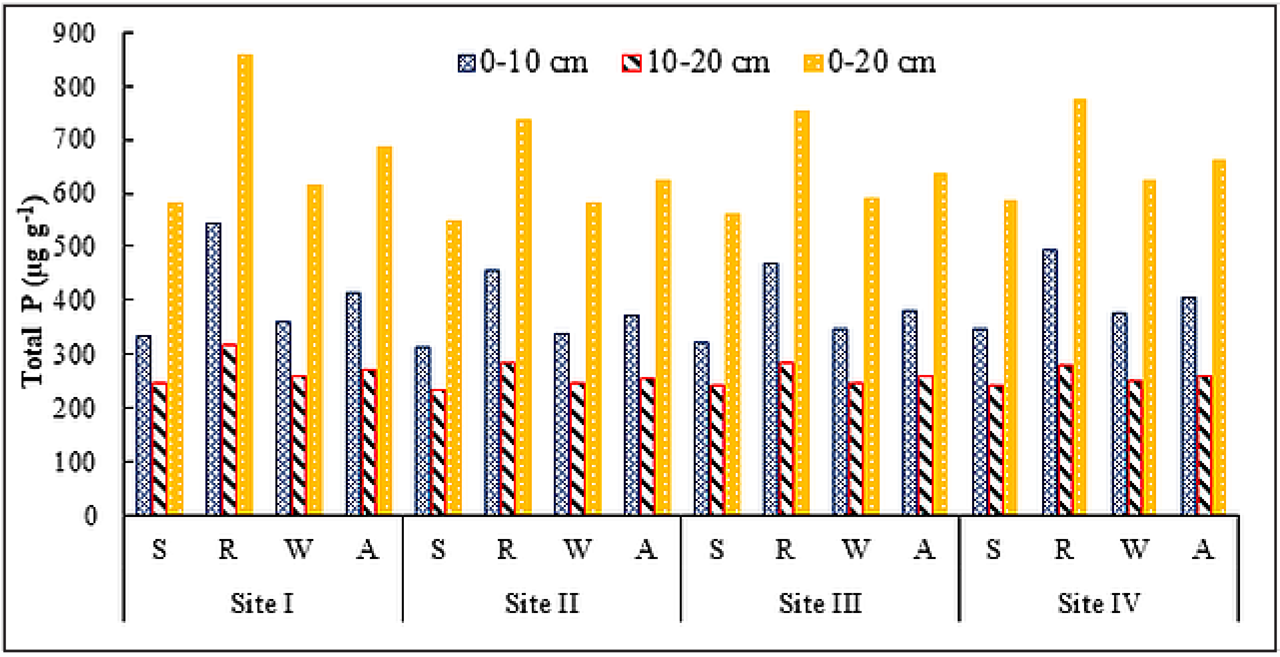

Figure 9. Seasonal variation Total P (µg g^{-1}) in the recent slash and burnt site (site I), three year old fallow (site II), seven year old fallow (site III) and protected forest (site IV). S-Summer; R-Rainy; W-Winter; A-Annual

weathered tropical soils, the availability of phosphorous may depend more on turnover of easily decomposable soil organic matter than on the adsorption of inorganic phosphate Pi (Tiessan et al. 1992). Decomposition of organic matter is an important mechanism of phosphorous dynamics (Hands et al. 1995). In general P release is increased when crop residues are allowed to decompose on the soil surface. At least 75% of the P in surface soil is found in soil organic matter, which emphasizes the importance of soil organic matter in the supply of this element (Hands et al. 1995).

The mean annual value of total soil phosphorous was highest in site I and lowest in site II. The high total soil phosphorous levels in site I may be due to ash addition. Many studies have related increase in total soil phosphorous due to ash addition (Debano and Conrad 1978, Andriessae and Koopmans 1984, Kutiel and Navech 1987). The limiting effect of ash that revised the pH and reduced phosphorous fixation in the soil favoring the activity of microorganisms may also contribute to raise in P levels (Juo and Manu 1996) at site I.

The low mean annual value of total phosphorous in site II may be due to sharp decline in total phosphorous during cropping and harvesting period as P is rapidly absorbed by the growing crops followed by run off and soil erosion due to decline in plant cover by harvesting. In comparison, Ketterings et al. (2002) found that losses of P due to leaching, erosion and/or harvest removal are limited under forest cover and P accumulates in the above ground biomass. In the present study, total soil phosphorous levels in site III 1900.33 $\mu g\ g^{-1}$ of soil were found to be close to those of site IV 1978.50 $\mu g\ g^{-1}$ of soil which is in conformity with the report of Yemefack et al. (2002) from virgin forest after seven years of natural fallow.

Ammonification

Seasonally, the ammonification rate was recorded to be maximum during rainy season followed by summer and winter seasons in all the sites in both the soil depths 0-10 and 10-20 cm except at site I (Table 5). The analysis of variance of ammonification indicated significant seasonal variations among the months of summer season $p<0.05$ and $p<0.01$, rainy season $p<0.01$, winter season $p<0.05$ and $p<0.01$ and annually $p<0.01$ in all the four sites at both the soil depths.

Seasonally the maximum ammonification rate was recorded during the rainy season in both the soil depths in all the four study sites which may be attributed to increased microbial activity due to congenial environment conditions for the ammonifiers. The rate of decomposition of plant litter is also high, thus, providing the substrate for microbes during this period. It is evident from the significant correlation between ammonification with soil moisture, soil organic carbon and total soil N. Increased flushes of microbial activity and nitrogen mineralisation on rewetting of dried soils have been

Table 5. Seasonal variation in the rate ($\mu g\ g^{-1} month^{-1}$) of Ammonification (Ammo), Nitrification (Nitri) and Mineralisation (Miner) in the recent slash and burnt site (site I), three year old fallow (site II), seven year old fallow (site III) and protected forest (site IV), * mean values of 0-20 cm soil depth

Season	Soil	Site I			Site II			Site III			Site IV		
	depth	**Ammo**	**Nitri**	**Miner**	**Ammo**	**Nitri**	**Miner**	**Ammo**	**Nitri**	**Miner**	**Ammo**	**Nitri**	**Miner**
Summer	0-10	2.89	2.93	5.91	3.03	2.29	5.32	3.73	2.25	5.98	3.56	2.63	6.19
	10-20	2.78	2.13	4.91	2.18	1.56	3.74	2.90	1.61	4.51	2.30	1.85	4.15
	0-20*	2.83	2.53	5.36	2.60	1.92	4.52	3.31	1.93	5.24	2.93	2.24	5.17
Rainy	0-10	7.65	5.35	13.00	3.27	4.08	7.35	5.29	3.69	8.97	6.19	2.85	9.04
	10-20	5.67	4.64	10.31	2.53	2.81	5.34	4.36	2.80	7.16	4.93	2.39	7.32
	0-20*	6.66	4.99	11.65	2.90	3.44	6.34	4.82	3.24	8.06	5.56	2.62	8.18
Winter	0-10	3.51	2.17	5.68	1.94	1.70	3.66	2.69	1.63	4.32	3.03	1.72	4.75
	10-20	2.59	1.80	4.39	1.53	1.38	2.91	2.16	1.33	3.49	2.27	1.37	3.64
	0-20*	3.05	1.98	5.03	1.73	1.54	3.27	2.42	1.47	3.89	2.65	1.54	4.19
Annual	0-10	4.68	3.48	8.16	2.75	2.69	5.44	3.90	2.52	6.42	4.26	2.40	6.66
	10-20	3.68	2.86	6.54	2.08	1.92	4.00	3.14	1.91	5.05	3.17	1.87	5.04
	0-20*	4.18	3.17	7.35	2.41	2.30	4.72	3.52	2.21	5.73	3.71	2.13	5.30

reported by Bloem et al. (1992) and Franzluebbers et al. (2000). Similar seasonal variation in ammonification rate was reported by Maithani et al. (1998), Usman et al. (1998) and Devi and Yadava (2005).

However, the minimum rate of ammonification was found during winter season in all the study sites except in site I, where it is lowest in summer season. The minimum rate of ammonification found in winter season in site-II, site-II and site-IV may be due to immobilization of inorganic-N by micro-organisms. The activities of the ammonifiers also become dormant due to cool and dry climatic conditions. It is lowest in summer season in site I which may be due to more exposure to sunlight due to lack of plant cover as compared to the other three sites leading to increased soil dryness making the soil unfavourable for microbial activity. Similar moisture limited seasonality was reported by Singh et al. (1991) in dry tropical Savanna, Gonclaves and Carlylet (1994) from plantation of south eastern, South Australia, Maithani (1998), Usman et al. (1998) and Devi and Yadava (2005) from forest stands of north east India. The present rate of ammonifcation 1.22 to 9.12 μg g^{-1} $month^{-1}$ is within the range reported by Knoeep and Swank (1993) 1.70 to 9.50 μg g^{-1} $month^{-1}$ in southern Applachian pine hardwood forest stands, Maithani et al. (1998) 0.60 to 9.90 μg g^{-1} $month^{-1}$ in a sub-tropical forest north-east India. However, slightly lower range of ammonification (0.90 to 6.90 μg g^{-1} $month^{-1}$) was reported by Devi and Yadava (2005) in *Dipterocarpus* forests of Manipur.

There was significant correlation between the rates of ammonification with soil moisture in all the study sites in both soil depths (Tables 1, 2, 3, 4) which indicates the influence of soil moisture in the ammonification process. Similar significant correlation between ammonification and soil moisture was reported by Singh et al. (1991), Morecroft et al. (1992), Usman et al. (1998), De Neve and Hofman (2003) and Devi and Yadava (2005).

There was significant correlation between ammonification rate with total soil organic C and total soil N in all the four study sites (Tables 1, 2, 3 4)**.** This correlation supports that increase in loading of soil organic C and total soil N leads to enhancement in the activities of microorganism, thereby, increasing the rate of ammonification. Similar significant correlation was reported by Motavalli et al. (1995), Li et al. (2003) and Devi and Yadava (2005).

The positive correlation of ammonification rate with soil temperature and soil pH (Tables 1, 2, 3, 4) in the present study indicates the regulating effect of temperature and moisture on ammonification. Moisture and temperature are considered major edaphic factors controlling mineralisation of N (Campbell et al. 1994). Similar significant correlation was reported by Gonclaves and Carlyle (1994), Motavalli et al. (1995) and Curtin et al. (1998).

Nitrification

Seasonally, the rate of nitrification was recorded to be highest in the rainy season followed by summer season and winter season in all the four sites at both the soil layers 0-10 and 10-20 cm. The analysis of variance indicated significant seasonal variations between the months of summer season $p<0.01$, rainy season $p<0.01$, winter season $p<0.05$ and $p<0.01$ and annualy $p<0.01$ in all the four sites in both soil depths (Table 5)**.**

Seasonally maximum rate of nitrification was recorded during rainy season in all the four study sites in both the depths which is obvious due to favorable temperature and soil moisture condition for the nitrifiers during this period. Myers (1975) has suggested that nitrification has been known to approximate bell shaped curve with optimism at 30-35°C. Maithani (1998), Knoepp and Swank (1998), Devi and Yadava (2005) also reported higher rate of nitrification during the growing season. However, the lowest rate of nitrification was found during the winter season in all the four study sites in both the depths which may be attributed to cool and dry season thereby reducing microbial activity. Ghosal et al. (2002) found that due to low water potentials under dry land conditions, the activity of nitrifying bacteria in contrast to diverse ammonifying microbes is retarded.

The present rate of nitrification 0.80 to 6.81 μg g^{-1} falls within the range reported by Singh et al. (1991) 0.80 to 15.00 μg g^{-1} in a dry tropical savanna; Usman et al. (1998) 1.00 to 8.00 μg g^{-1} soil in Chir pine forest site of Central Himalya, Knoepp and Swank (1998) 1.0 to 16.00 μg g^{-1} soil in the northern hardwood site of the southern Appalachians. A comparatively lower range of 0.47 to 3.21 μg g^{-1} was however reported by Yadava and Devi (2005).

In the present study there was significant correlation between the rate of nitrification with soil moisture, soil temperature, total soil organic carbon, total soil N and pH (Tables 1, 2, 3, 4) in all the study sites**.** Similiar significant correlation have been reported by Myers et al. (1975), Sahrawat et al. (1982), Gilmour et al. (1984), Usman et al. (1998), Maithani et al. (1998), De Boer and Kowalchuk (2000), Jussy et al. (2002), Tanaka et al. (2002), Li et al. (2003) and Devi and Yadava (2005).

In the present study, higher rates of ammonification were recorded in all the four study sites compared to nitrification rates. Probably, the higher soil temperature induced by slash and burn treatment favours ammonification which is a more thermophilic process compared to nitrification since the range 50-70pC is widely quoted as being optimal for ammonification (Harmsen and Kolebrander 1965, Myers 1975).

N-mineralisation

Seasonally, the rate of N-mineralisation was highest during the rainy season followed by summer season and winter seasons in all the sites in both the soil depths except in site I where it was Rainy> Winter> Summer in 10-20cm soil depth (Table 5). The Analysis of Variance indicated significant seasonal variation among the months of summer season $p<0.05$ and $p<0.01$, rainy season $p<0.01$ winter season $p<0.01$ and annually $p<0.01$ in all the four sites in both the soil depths.

Seasonally, the rate of N-mineralisation was highest during the rainy season in all the four study sites in both the years of the study period across the soil depths. This may be due to optimum soil moisture conditions and temperature for microbial activity leading to higher rate of decomposition. It may also be due to higher demand of nitrate and ammonium -nitrogen by the actively growing vegetation which enhances mobilization of inorganic nitrogen. Similar results were reported by Goncalves and Carlyle (1994) which shows that N-mineralisation in maximum when the soil is moist and temperature is moderate. The higher rate of N-mineralisation during rainy season was reported by Usman et al. (1998), Maithani et al. (1998), Sadras and Baldock (2003) and Devi and Yadava (2005). However, the lowest rate of N-mineralisation was found during winter season in all the sites except site I in both the soil depths throughout the study period, may be due to the slow rate of decomposition attributable to low microbial activity which might have resulted in greater immobilization of nitrogen as soil moisture was very low. In the summer season it is lowest in site I, which may be due to immobilization of the nutrients by microbes. The lower rates of N-mineralisation in the relatively dry summer period and cool and dry winter period may indicate the strong influence of soil moisture content on N-mineralisation. Apparently, N-mineralisation is moisture limited. Seasonal variation in in-situ nitrogen mineralisation has been reported in several studies and is often associated with changes in soil moisture or temperature (Raison et al. 1987, Smethrust and Nambiar 1990, Gonclaves and Carlyle 1994). Moisture limited seasonality in nitrogen mineralisation has also been reported by Singh et al. (1991) in a dry tropical Savanna, Devi and Yadava (2005) in the Dipterocarpus forest of Manipur, north east India.

The nitrogen mineralisation rate recorded in the present study, i.e., 3.64 to 15.70 μg $g^{-1}$$month^{-1}$ in site I, 2.49 to 9.92 μg g^{-1} $month^{-1}$ in site II, 2.76 to 11.80 μg g^{-1} $month^{-1}$ in site III and 2.78 to 11.80 μg g^{-1} $month^{-1}$ in site IV are within the range reported by Singh et al. (1991) in protected dry tropical forest (0.8 to 15.0 μg g^{-1} $month^{-1}$) and in a burned forest ecosystem (0.2 to 23 μg g^{-1} $month^{-1}$), Knoepp and Swank (1998) from an elevation gradient in the Southern Appalachians (1.9 to 33 μg g^{-1} $month^{-1}$), Rasmussen et al. (1998) in cropped and fallow fields at Pendleton Oregon (6.40 to 22.7 μg g^{-1} $month^{-1}$). However, slightly higher rate of N mineralisation was recorded from that obtained by Yadava and Devi (2005) from the Dipterocarpus forest of Manipur in the protected forest site (1.41 to 7.75 μg g^{-1} $month^{-1}$) and in the slash and burnt site (0.82 to 9.54 μg g^{-1} $month^{-1}$).

The nitrogen mineralisation rate was positively correlated to soil moisture in the present study in all the four study sites in both the soil depth (Tables 1, 2, 3, 4).The relation signifies that soil moisture is an important factor in regulating the rate of N-mineralisation. Leiros et al. (1999) have reported a linear relationship between mineralisation and soil moisture in woodlands of Galicia north-west Spain. Besides this there exists a positive correlation with soil organic C and total soil N (Tables 1, 2, 3, 4) indicating the importance of organic substrate for N-mineralisation. Similiar positive correlation was also reported by Tanaka et al. (2002), Li et al. (2003), Devi and Yadava (2005). The rate of nitrogen mineralisation also was positively correlated to soil temperature and pH in all the study sites indicating that soil temperature and pH (Tables 1, 2, 3, 4) are also the important factors influencing N-mineralisation. Similar positive correlation was also reported by Curtin et al. (1998), Maithani et al. (1998), Li et al. (2003) and Paul et al. (2003).

Comparison among the four study sites indicates the rate of ammonification and N-mineralisation was highest in site I followed by site IV and site III and site II. However, the rate of nitrification was found highest in the site I followed by site II, site III and site IV. The highest rate of ammonification, nitrification and N-mineralisation in the site I may be due to the addition of decomposable substrate in the soil on slash and burning treatment leading to higher content of total soil organic C and total soil N as evident from the significant correlations. Ash input is also one of the major sources of increase in the content of mineral N and may increase pH in the site I. It is also evident from the significant correlation between the rate of ammonification, nitrification and N-mineralisation with soil pH. The lowest rate of ammonification and N-mineralisation observed in site II may be due to the lack of ground cover during early fallows. This leads to possible losses of nutrients due to leaching, runoff and erosion during the cropping phase and early fallows. Tawenga et al. (1997) also emphasized the importance of soil erosion and nutrient loss especially for sloppy sites in hot humid high rain fed areas. Tanaka et al. (2002) reported that organic matter and the ability to supply mineral N continued to decrease until 3 to 5 years of fallow regrowth, probably because of poor vegetation cover and stimulation to decompose soil organic matter due to repeated dry and wet cycles. The slightly higher rate of ammonification and N-mineralisation observed in site III may be because it has sufficient time to recover. Tanaka et al. (2002) also found that soil organic matter recovered enough to supply nitrogen within 8 years of fallow regrowth. Singh et al. (2003) also reported enhancement of nutrients due to regrowth of vegetation in older fallows. Lower nitrification rate in site IV may be due to higher acidity of the forest soil pH 5.08. Soil pH is recognized as an important regulator of microbial activity (Curtin et al. 1998). Dancer et al. (1973) showed that mineralisation was not affected by pH in the range 4.7 to 6.6 but nitrification decrease 3 to 5 fold as pH decreased.

CONCLUSIONS

In the present study, the nutrient status soil organic carbon, nitrogen and total phosphorous of soil in site-I was comparatively higher than the other three sites. This may be attributed due to the addition of organic matter in the form of ash and partly burnt plant materials in site I on slash and burning operation performed just before the onset of the present study. The enhancement of organic matter leads to higher activities of the soil microorganisms, thereby giving by products in the form of soil nutrients mainly organic carbon and nitrogen through decomposition process. Relatively low level of microbial activity was observed in intact forest sites than in converted sites due to higher organic carbon and supply more readily available organic matter to the soil microbial community by the actively growing young vegetation.

Thus, conversion of forest into agricultural land through slash and burning resulted in an initial increase in the amount of soil nutrients as the ashes from the burnt vegetation biomass act as fertilizer. In the short term, the rate of ammonification, nitification and mineralisation are enhanced. However this effect is short lived as shown by the depleted nutrient level and low rate of ammonification, nitification and mineralisation in site II and in site III the soil nutrient levels and rate of ammonification, nitification and mineralisation show significant recovery. This result support the opinion that shifting cultivation in its tradition form with short cropping period and long farrow periods is ecologically sustainable whereas intensive land use as being increasing practiced at present due to population pressure and shortage of land, prevent long fallow interval to regenerate the productivity of the soil. Therefore, for an appropriate land management in this region the knowledge of traditional shifting cultivation is applied to arrest the decline in the fertility of the soil.

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